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EOC/ICC Trade Study Report for the ECS Project

Working Paper

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RESPONSIBLE ENGINEER

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Contents

Contents

1. Introduction

2. FOS Baseline

3. FOS Alternative

4. Trades

Abbreviations and Acronyms

1. Introduction

1.1 Purpose

The purpose of the EOC/ICC Trade Study was to compare and contrast two architectures for the Flight Operations Segment (FOS) of the EOSDIS Core System (ECS). The baseline architecture consists of an EOS Operations Center (EOC), Instrument Control Centers (ICCs), and Instrument Support Terminals (ISTs). This architecture is outlined in the Functional and Performance Requirements for the ECS Project (DID 216/SE1). The alternative architecture consists of an EOC Operations Center and Instrument Support Terminals. This architecture is outlined in the EOSDIS FOS Operations Concept Document (March 1993) prepared by Computer Science Corporation for NASA. The scope of this paper is limited to functional architecture and does not present the FOS software architecture. The FOS software architecture will be presented at the appropriate ECS reviews (System Design Review, Preliminary Design Review, Incremental Design Reviews and Critical Design Reviews).

The baseline architecture identified a need for separate, physical ICCs based on the potentially complex nature of operating the instrument manifests associated with the EOS missions. Instrument operations were believed to be potentially complex requiring support of Data Acquisition Requests (DARs). A DAR is a mechanism by which the science user requests science data from instruments that do not have exclusively repetitive data acquisition cycles. Typically, this mechanism applies to instruments with targeting capabilities.

The alternative architecture, which eliminated separate, physical ICCs, was subsequently identified based on the reduced complexity of operating the instruments. Operations would be performed primarily via baseline activity profiles and would not require DAR support. The baseline activity profile defines the schedule of activities for a target week corresponding to normal instrument operations and is constructed from the long term instrument plan. Centralizing instrument operations at the EOC allows commonality between diverse instrument operations to be exploited. Additionally, the alternative architecture would be flexible enough to allow the PI/TL to perform an increased role in instrument operations, if desired.

It is important to note that the FOS architecture must be evolvable. The alternative architecture must in the future be able to support an ICC for an instrument thats complexity warrants one. One approach for supporting a complex instrument in the future would be to: 1) reuse the International Partner (IP) ICC interface being developed for the ASTER instrument and 2) repackage the applicable EOC functionality as an ICC. A second approach would be to expand the EOC/IST architecture to support a more complex instrument.

1.2 Organization

This paper is organized as follows:

Section 2.0 provides a summary of the baseline FOS architecture and the corresponding operations concept. Section 3.0 provides the alternative architecture and its corresponding operations concept. Section 3.1 outlines the baseline ICC functionality as it would be allocated to the alternative architecture. Section 3.1.1 describes the functions that would migrate to the EOC and section 3.1.2 describes the functions that would be negotiable (i.e. these functions would be allocated to either the EOC or the IST on an instrument by instrument basis.) Finally, section 4.0 provides a trade analysis for the FOS software, hardware, and operations.

1.3 Review and Approval

This document is an informal contract deliverable approved at the Office Manager level. It does not require formal Government review or approval; however, it is submitted with the intent that review and comments will be forthcoming.

The ideas expressed in this White Paper are valid for June 1994; the concepts presented here are expected to migrate into the following formal CDRL deliveries:

Table 1-1. White Paper to CDRL Migration

White Paper Section	CDRL DID/Document Number
4.0 Trades	Operations Concept Document for the ECS Project 604/OP1

Questions regarding technical information contained within this Paper should be addressed to the following ECS and/or GSFC contacts:

- ECS Contacts
  - Deborah P. Dunn, FOS Real-Time Supervisor, 301-925-0620, ddunn@eos.hitc.com
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2. FOS Baseline

2.1 FOS Baseline Architecture

The Baseline FOS architecture, as outlined in the Functional and Performance Requirements for the ECS Project (DID 216/SE1), consists of the EOS Operations Center (EOC), Instrument Control Centers (ICCs), and Instrument Support Terminals (ISTs). Each of these elements interact functionally to plan, schedule, command, and monitor the operations of the EOS instruments and spacecraft. Figure 2-1 depicts a block diagram of the Baseline FOS Architecture.

2.1.1 EOS Operations Center

The EOC, located at Goddard Space Flight Center (GSFC), is the EOS mission operations center, and as such, is responsible for the mission critical operations of the U.S. EOS spacecraft and the onboard instruments. Included in these operations are: planning and scheduling spacecraft operations, coordinating instrument operations, commanding the spacecraft and instrument, maintaining spacecraft and instrument health and safety, monitoring spacecraft performance, performing spacecraft analysis, and monitoring instrument performance as it pertains to the mission. The EOC provides eight major services: planning and scheduling, command management, commanding, telemetry monitoring, spacecraft analysis, data management, element management, and user interfaces.

2.1.2 Instrument Control Center

The ICCs are responsible for planning, scheduling, commanding, and monitoring the operations of the U.S. instruments onboard the U.S. spacecraft. There is functionally one ICC for each U.S. instrument, all of which are located at GSFC. Each ICC works with the EOC to coordinate the planning and scheduling of its instruments' activities. The ICC also commands its instrument through the EOC. Additional operations are: monitoring spacecraft and instrument housekeeping telemetry and instrument engineering telemetry; monitoring instrument performance; and performing instrument analysis. The ICC provides nine major services: DAR processing; planning and scheduling; command management; commanding; telemetry monitoring; instrument analysis; data management; element management; and user interfaces.

2.1.3 Instrument Support Terminal

The IST toolkit allows the PI/TL to interface with the ICC and participate in various instrument activities including: DAR submittal, planning and scheduling, commanding, and monitoring. The IST provides the instrument capabilities at the PI/TL home facility, which is remotely located from the ICC. IST toolkits are provided for each U.S. instrument onboard a U.S. spacecraft.

2.2 FOS Baseline Operations Concept

The following paragraphs summarize the baseline operations concept for the FOS. For further detail, reference The ECS Operations Concept Document for the ECS Project, August 1993.

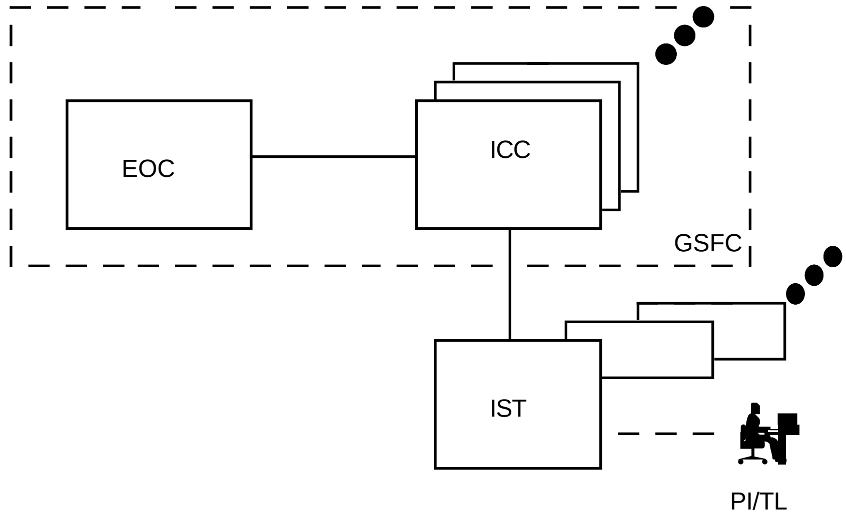

Figure 2-1. Baseline FOS Architecture

2.2.1 Planning and Scheduling

The baseline operations concept for planning and scheduling can be effectively categorized into three phases: long-term planning, initial scheduling, and final scheduling.

The EOC receives the Long Term Science Plan (LTSP) and the Long Term Instrument Plan from the System Management Center (SMC). These plans have been developed by the Project Scientist in collaboration with the Instrument Working Group (IWG) and the instrument principal investigators (PIs) and/or team leaders (TLs). The schedulers and engineers within the EOC then work with the project scientist to develop a long-term spacecraft operations plan, based on criteria defined in the LTSP and LTIP. The EOC generates the Baseline Activity Profiles (BAPs) for non-complex instruments based on the LTIPs.

The initial scheduling phase begins three to four weeks prior to the target week. The instrument schedulers at the ICC predict their instruments' resource requirements, allowing the EOC to negotiate with the Network Control Center (NCC) for Tracking Data Relay Satellite System (TDRSS) contact times.

For a non-complex instrument, the instrument scheduler and the PI/TL will coordinate any deviations to the BAP. The ICC is responsible for constraint checking any resource deviations and getting PI/TL approval for the resource deviations prior to submitting the deviation list to the EOC. The EOC scheduler will merge the BAP and any resource deviations to generate the instrument resource profile.

For a complex instrument, the instrument scheduler develops resource requirements from DARs, IST collection requests, instrument maintenance activities and instrument calibrations. Working with the PI/TL, the instrument scheduler uses these requirements to create an instrument resource profile. Once again, the ICC is responsible for constraint checking the resource profile and getting PI/TL approval prior to submitting the profile to the EOC.

The EOC scheduler is responsible for generating the spacecraft resource profile and integrating this with the instrument resource profiles. The overall resource profile is then used to generate formal requests to the NCC for TDRSS contact times. Approximately one week prior to the target week, the EOC Scheduler will provide the ICC with a preliminary resource schedule.

The final scheduling phase begins one week prior to the target week. The Instrument Scheduler develops a list of activities required for the instrument based on DARs, maintenance activities, calibrations, and/or spacecraft activities. For a non-complex instrument, an activity deviation list is created. For a complex instrument, an activity list is created. The instrument scheduler is responsible for constraint checking the activities and getting PI/TL approval prior to forwarding the activity list to the EOC. The EOC scheduler integrates all the instrument and spacecraft activities and performs conflict resolution to produce a detailed activity schedule. The EOC scheduler notifies the ICC of any activities that were rejected due to conflict. Some iteration of this process may then be required to finalize the detailed activity schedule.

2.2.2 Command Management

Two days prior to the target day the EOC scheduler and the ICC scheduler receive the detailed activity schedule. The ICC scheduler is responsible for the generation and validation of instrument microprocessor loads and instrument commands. The ICC forwards the instrument microprocessor loads and instrument commands to the EOC. The EOC scheduler is responsible for generating an integrated spacecraft load that includes: Spacecraft Control Computer (SCC)-stored commands and tables, flight software loads and updates, and instrument microprocessor memory loads. Additionally, the EOC scheduler generates corresponding ground scripts. The ground script contains directives necessary to uplink the integrated loads for each spacecraft, dump the spacecraft recorder and process real-time housekeeping data.

2.2.3 Real-Time Processing

The baseline operations concept for real-time processing can be effectively categorized into three phases: pre-contact, contact, post-contact. The EOC operations controller leads the shift operations, which encompass the three phases, for all spacecraft.

During the pre-contact phase, the EOC command activity controller initiates the EOC ground script in preparation for the upcoming contact. The ICC instrument evaluator initiates the ICC ground script, which coordinates any ground activities necessary in configuring the ICC for the upcoming contact.

Once contact with the spacecraft has been accomplished, both the EOC and ICC will automatically ingest and process real-time telemetry data. At the EOC the real-time telemetry data shall consist of spacecraft and instrument housekeeping telemetry data. At the ICC, the real-time telemetry data shall consist of spacecraft and instrument housekeeping telemetry data as well as instrument engineering telemetry data. The EOC spacecraft evaluator monitors the health and safety of the spacecraft and its subsystems, while each ICC instrument evaluator monitors the health and safety of their instruments. The PI/TLs, optionally, may also be monitoring the health and safety of their instrument. The EOC command activity controller coordinates and verifies all uplink activities during the contact. (Nominally, all real-time commanding is preplanned and facilitated by the EOC ground script. However, real-time commands may be initiated by: the EOC command activity controller, or the ICC instrument evaluator, with approval from the EOC command activity controller. Commands initiated by the ICC instrument evaluator include those initiated on behalf of the PI/TL via command requests.) The ICC instrument evaluator and the PI/TL at the IST are notified of the uplink status of instrument commands. The ICC instrument evaluator verifies command execution status for instrument commands.

During post-contact, the EOC and ICC automatically ingest spacecraft recorded telemetry data that was played back to the ground during the contact. The EOC spacecraft evaluator and the ICC instrument evaluator verify successful receipt of this data.

2.2.4 Spacecraft and Instrument Analysis

The Analysis service provides the EOC spacecraft engineers and the ICC instrument engineers with a set of tools to perform: trend analysis, performance analysis, resource management, configuration management and anomaly resolution for each spacecraft and its instruments. The EOC spacecraft engineers routinely analyze housekeeping telemetry trend data on the spacecraft subsystems to identify performance fluctuation issues. Upon identifying a problem, the EOC spacecraft engineer recommends a corrective action. If the corrective action is not time critical, it is scheduled as a spacecraft activity by the EOC scheduler. If the corrective action is time critical, the corrective action will be performed by the EOC command activity controller during the next available contact. Similarly, the ICC instrument engineer may recommend corrective action for an instrument. Depending on the time criticality, either the ICC instrument scheduler schedules an instrument activity or the ICC instrument evaluator performs the corrective action during the next available contact.

3. FOS Alternative

3.1 FOS Alternative Architecture

The alternative FOS architecture under consideration for this trade consists of the EOS Operations Center (EOC) and Instrument Support Terminals (ISTs). The ICC functionality is folded into the EOC and the ISTs. Additionally, the alternative architecture would be flexible enough to allow the PI/TL to perform an increased role in instrument operations. Figure 3-1 depicts the alternative FOS architecture. This architecture may prove a more appropriate solution, since the current manifest indicates none of the U.S. instruments may be complex enough to warrant a separate ICC functionality. If a separate, physical ICC becomes a necessity in the future, this architecture could be expanded to include it.

The ICCs responsibilities of planning, scheduling, commanding and monitoring the operations of U.S. instruments onboard U.S. spacecraft, would be divided between the EOC and the PI/TL using the IST toolkit. All mission critical ICC functions/responsibilities would be assigned to the EOC. The IST toolkit interfaces with the EOC to allow the PI/TL to participate in various instrument activities. Additionally, a set of functions would be accessible to the PI/TL via the IST, allowing them to perform an increased role in instrument operations if desired. It should be noted that these additional functions can be negotiated at the service level (e.g. an instrument team may choose to perform their own analysis, but may desire that planning and scheduling be performed at the EOC). The functions allocated in sections 3.1.1 and 3.1.2 can be directly mapped to the ICC Requirements, section 6.5.2.3 of the Functional and Performance Requirements for the ECS Project (DID 216/SE1). Allocation of these functions do not imply a software architecture/design.

Note: Italics in the following sections denote changes from the baseline architecture.

3.1.1 EOS Operations Center

The EOC is the EOS mission operations center, and as such, is responsible for the mission critical operations of the U.S. EOS spacecraft and the instruments onboard. There is a single EOC and it is located at the Goddard Space Flight Center (GSFC). Included in these operations are: planning and scheduling of spacecraft operations *and instrument activities,* coordinating instrument operations, commanding the spacecraft and instruments, maintaining spacecraft and instrument health and safety, *monitoring instrument engineering telemetry,* monitoring spacecraft *and instrument* performance, and performing spacecraft *and instrument* analysis. The EOC provides nine major services: *DAR processing,* planning and scheduling, command management, commanding, telemetry monitoring, analysis, data management, element management, and user interfaces.

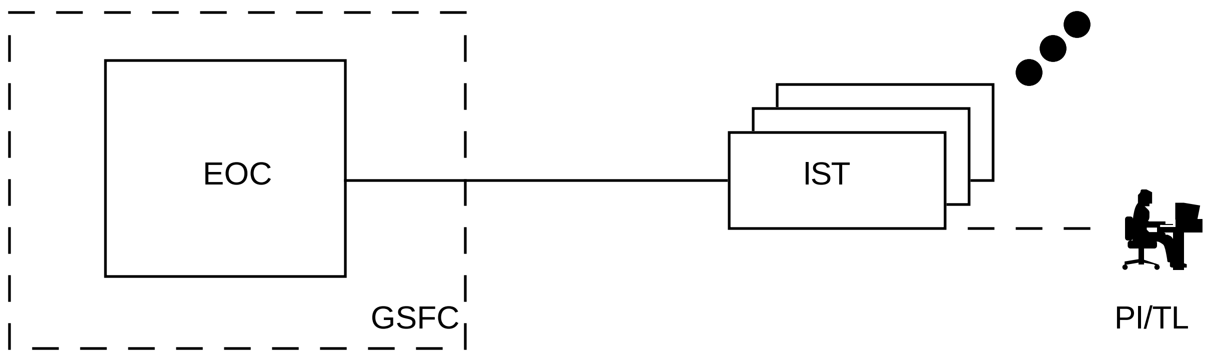

Figure 3-1. Alternative FOS Architecture

3.1.1.1 Planning and Scheduling/DAR Processing

A subset of the baseline ICC Planning and Scheduling functions and DAR processing functions will be allocated to the EOC. Tables 3-1 and 3-2 summarize these functions. In general, these functions are best realized through the central coordination the EOC can provide.

Table 3-1. Planning and Scheduling: ICC to EOC Function Migration

Function	Justification
Allow IST access to planning and scheduling functions	The planning and scheduling functions are distributed between the EOC and the IST
Provide the IST with planning and scheduling information	The planning and scheduling functions are distributed between the EOC and the IST
Notify the IMS of the planned or scheduled observation times associated with DARs	Planning and scheduling coordination is the responsibility of the EOC; the EOC will be the central repository of the current negotiated plans and/or schedules
Accept requests for instrument support activities and notify IST of receipt	The EOC will provide this function in cases where it was responsible for instrument planning and scheduling
Request the IST to aid in conflict resolution	The EOC will provide this function in cases where it was responsible for instrument planning and scheduling
Update, for historical purposes, the instrument activity list or deviation based on issuance of unscheduled commands	The EOC will provide this function based on the accessibility of command history information
Update instrument activity list or deviation list in support of TOOs, late changes, or anomalies	This function requires 24 hour support and therefore will be handled by the EOC.

Table 3-2. DAR Processing: ICC to EOC Function Migration

Function	Justification
Provide IMS with instrument information needed for DAR generation	This function will be performed by the EOC, which serves as the central repository for instrument information
Generate and submit DARs to the IMS	This function will be available to the EOC; it will also remain a capability available to the IST
Send DAR evaluation request to the IST	The EOC will provide this function in cases where it is responsible for instrument DAR processing
Accept DARs in support of TOOs	This function requires 24 hour support and therefore will be handled by the EOC.

3.1.1.2 Command Management

Most of the baseline ICC Command Management functions will be allocated to the EOC. Table 3-3 summarizes these functions. In general these function are deemed mission critical and include command generation for the Spacecraft Control Computer (SCC).

Table 3-3. Command Management: ICC to EOC Function Migration

Function	Justification
Generate and validate SCC-stored instrument commands and tables	Mission critical function allocated to the EOC. All SCC-stored commands and tables are built within the EOC.
Generate and validate SCC-stored instrument commands and tables in support of TOOs, late changes, and anomalies	Mission critical function allocated to the EOC. All SCC-stored commands and tables are built within the EOC.
Generate, validate and store pre-planned SCC-stored instrument commands and tables	Mission critical function allocated to the EOC. All SCC-stored commands and tables are built within the EOC.
Accept instrument memory loads, including software and table updates from PI/TL via the IST	The IST will provide this information to the EOC so that it can be incorporated into the integrated load

3.1.1.3 Commanding and Telemetry Processing

All of the baseline ICC Commanding and Telemetry Processing functions will be allocated to the EOC. Tables 3-4 and 3-5 summarize these functions. In general, these functions are real-time mission critical functions for control and monitor of a spacecraft and its instruments.

Table 3-4. Commanding: ICC to EOC Function Migration

Function	Justification
Accept and evaluate instrument command requests from the IST	Interface requirement between EOC-ICC-IST now between EOC-IST
Generate and validate preplanned instrument command groups in response to IST command requests	Interface requirement between EOC-ICC-IST now between EOC-IST
Generate and validate emergency/contingency command groups	Mission critical function allocated to EOC. All emergency/contingency operations are performed by the EOC.
Retrieve and execute stored instrument command groups	Mission critical function allocated to EOC. Real-time commanding functions are performed by the EOC.
Verify successful receipt and execution of instrument commands	Mission critical function allocated to EOC. Real-time commanding functions are performed by the EOC.
Provide IST with instrument command status (receipt and execution)	Interface requirement between EOC-ICC-IST now between EOC-IST

Table 3-5. Telemetry Processing: ICC to EOC Function Migration

Function	Justification
Provide the IST with instrument housekeeping and engineering data and spacecraft housekeeping data	Interface requirement between EOC-ICC-IST now between EOC-IST
Monitor instrument housekeeping, engineering and memory dump data	Mission critical function allocated to EOC. Real-time monitoring functions are performed by the EOC.
Process spacecraft recorded instrument housekeeping and engineering data	Mission critical function allocated to EOC. Real-time monitoring functions are performed by the EOC.

3.1.1.4 Instrument Analysis

A subset of the baseline ICC Instrument Analysis functions will be allocated to the EOC. Table 3-6 summarizes these functions. In general, all interfaces with EDOS will be via the EOC.

Table 3-6. Instrument Analysis: ICC to EOC Function Migration

Function	Justification
Accept quicklook data in CCSDS packets from EDOS	The EDOS interface will be to the EOC, all CCSDS packet processing will be performed by the EOC, the quicklook data will be passed to the IST via the EOC

3.1.1.5 Data Management and Element Management

All of the baseline ICC Data Management and Element Management functions will be allocated to the EOC. Tables 3-7 and 3-8 summarize these functions. The Data Management and Element Management services are support services for mission critical operations such as Commanding and Telemetry Processing.

Table 3-7. Data Management: ICC to EOC Function Migration

Function	Justification
Maintain the instrument data base	Mission critical function allocated to EOC. Centralized configuration control of data bases are the responsibility of the EOC.
Maintain instrument history log	Mission critical function allocated to EOC. Centralized logging of the instrument operations activity is the responsibility of the EOC.

Table 3-8. Element Management: ICC to EOC Function Migration

Function	Justification
Control and monitor configuration of resources, monitor performance, generate reports, provide operations testing.	Mission critical function allocated to EOC. Centralized control and monitoring of the EOC element is a function of the EOC.
Coordinate operations with EDOS and the SMC	Mission critical function allocated to EOC. Operations coordination is a centralized function of the EOC.

3.1.2 EOC/IST Functions

The IST toolkit allows the PI/TL to interface with the EOC and participate in various instrument activities including: DAR submittal, planning, scheduling, commanding, and monitoring. The IST provides the instrument capabilities at the PI/TL home facility, which is remotely located from the EOC. IST toolkits are provided for each U.S. instrument onboard a U.S. spacecraft.

3.1.2.1 Planning and Scheduling / DAR Processing

The majority of the baseline ICC Planning and Scheduling and DAR Processing functions and responsibilities can be negotiated on an instrument by instrument basis. Tables 3-9 and 3-10 summarize these functions. The Planning and Scheduling / DAR Processing are tightly coupled, since the DAR processing service feeds the Planning and Scheduling service. These functions are performed by the party, either the EOC Scheduler or PI/TL at the IST, identified as primary for the planning and scheduling of a given instrument. Note that all the functions listed in tables 3-9 and 3-10 would be bundled; the party with the primary role is responsible for all of these functions (i.e. responsibilities for these functions are not negotiated at a finer granularity).

Table 3-9. Planning and Scheduling: EOC/IST Functions

Function	Justification
Identify and resolve instrument conflicts in the plans and schedules	This function must be performed by the party identified with the primary planning and scheduling role
Reintroduce applicable requested activities in the planning and scheduling function when the activity did not occur due to a deviation from the schedule	This function must be performed by the party identified with the primary planning and scheduling role
Convert a DAR into scheduling directives suitable for inclusion in the instrument plans and schedules	This function must be performed by the party identified with the primary planning and scheduling role
Plan and schedule instrument maintenance activities	This function must be performed by the party identified with the primary planning and scheduling role
Build instrument resource profile or instrument resource deviation list	This function must be performed by the party identified with the primary planning and scheduling role
Generate or update the instrument activity list or instrument activity deviation list	This function must be performed by the party identified with the primary planning and scheduling role

Table 3-10. DAR Processing: EOC/IST Functions

Function	Justification
Receive, evaluate and process DARs and DAR updates from the IMS	This function must be performed by the party identified with the primary DAR processing role
Processing a DAR requiring coordination between multiple instruments	This function must be performed by the party identified with the primary DAR processing role
Maintain a record of DARs for inclusion in plans and schedules	This function must be performed by the party identified with the primary DAR processing role

3.1.2.2 Command Management

A subset of the baseline ICC Command Management functions and responsibilities can be negotiated on an instrument by instrument basis. Table 3-11 summarizes these functions. These functions are performed by the party, either the EOC Scheduler or the PI/TL at the IST, identified as primary for the command management of a given instrument. Generally, the responsibility for generating and managing instrument loads can be performed at either the EOC or the IST. Note that all the functions listed in table 3-11 would be bundled; the party with the primary role is responsible for all of these functions (i.e. responsibilities for these functions are not negotiated at a finer granularity).

Table 3-11. Command Management: EOC/IST Functions

Function	Justification
Generate and validate instrument loads	This function will nominally be performed by the PI/TL, but can be a function of either the IST or the EOC. (The PI/TL is responsible for providing the necessary algorithms when this function is to be performed by the IST or EOC.) Note: Instrument Flight Software Loads remain the responsibility of the PI/TL.
Generate command-to-memory location map for instrument-stored command loads	This function is tightly coupled with the generation and validation of instrument loads.

3.1.2.3 Commanding and Telemetry Processing

All of the ICC Commanding and Telemetry Processing functions and responsibilities are deemed mission critical and therefore are non-negotiable. These functions will reside wholly within the EOC.

3.1.2.4 Instrument Analysis

The majority of the baseline ICC Instrument Analysis functions and responsibilities can be negotiated on an instrument by instrument basis. Table 3-12 summarizes these functions. These functions are performed by the party, either the EOC Instrument Engineer or the PI/TL at the IST, identified as primary for the analysis of a given instrument. Note that all the functions listed in table 3-12 would be bundled; the party with the primary role is responsible for all of these functions (i.e. responsibilities for these functions are not negotiated at a finer granularity).

Table 3-12. Instrument Analysis: EOC/IST Functions

Function	Justification
Perform analysis on instrument data: real-time and spacecraft recorded	This function must be performed by the party identified with the primary instrument analysis role
Accept and display quicklook products from DADS	This function must be performed by the party identified with the primary instrument analysis role
Process and display quicklook data	This function must be performed by the party identified with the primary instrument analysis role
Manage instrument-specific operations	This function must be performed by the party identified with the primary instrument analysis role
Monitor and evaluate instrument environmental parameters	This function must be performed by the party identified with the primary instrument analysis role
Monitor instrument configuration, trends and performance	This function must be performed by the party identified with the primary instrument analysis role
Recommend instrument reconfigurations	This function must be performed by the party identified with the primary instrument analysis role
Maintain and validate master ground image for instrument memory	This function must be performed by the party identified with the primary instrument analysis role

3.1.2.5 Data Management and Element Management

All of the ICC Data Management and Element Management functions and responsibilities are deemed mission critical and therefore are non-negotiable. These functions will reside wholly within the EOC.

3.2 FOS Alternative Operations Concept

The following paragraphs outline the alternative operations concept for the FOS. The emphasis is to highlight changes from the baseline as documented in The ECS Operations Concept Document for the ECS Project, August 1993 (DID 604/OP1).

Note: Italics in the following sections denote changes to the baseline operations concept.

3.2.1 Planning and Scheduling

The alternative operations concept for planning and scheduling can be effectively categorized into three phases: long-term planning, initial scheduling, and final scheduling. The long-term planning phase as described in section 2.2.1 remains unchanged in the FOS alternative operations concept. Note that whenever the EOC is assigned primary responsibility for the planning and scheduling of an instrument, the EOC will coordinate and consult with the PI/TL. (This remains consistent with the role as it was described in the baseline for the ICC.)

The initial scheduling phase begins three to four weeks prior to the target week. *For some instruments, on a pre-negotiated basis, the PI/TL at the IST predicts their instruments' resource requirements. For the remaining instruments,* the instrument schedulers at the *EOC* predict the instruments' resource requirements. With this information the EOC can negotiate with the NCC for TDRSS contact times.

For a non-complex instrument, either the instrument scheduler in coordination with the PI/TL at the IST *or the PI/TL at the IST* will develop deviations to the BAP. The *EOC* is responsible for constraint checking any resource deviations and getting PI/TL approval for the resource deviations prior to submitting the deviation list to the EOC scheduler*, for all instruments assigned to it. Similarly, the PI/TL at the IST is responsible for constraint checking any resource deviations prior to submitting the deviation list to the EOC scheduler, if primary planning and scheduling responsibility has been assigned to the PI/TL.* The EOC scheduler will merge the BAP and any resource deviations to generate the instrument resource profile.

For a complex instrument, the instrument scheduler in coordination with the PI/TL at the IST *or the PI/TL at the IST* develops resource requirements from DARs, instrument maintenance activities and instrument calibrations. The instrument scheduler *or the PI/TL at the IST* uses these requirements to create an instrument resource profile. Once again the *EOC* is responsible for constraint checking the resource profile and getting PI/TL approval prior to submitting the profile to the EOC Scheduler*, for all instruments assigned to it. Similarly, the PI/TL at the IST is responsible for constraint checking the resource profile prior to submitting the profile to the EOC Scheduler, if primary planning and scheduling responsibility has been assigned to the PI/TL.*

The EOC scheduler is responsible for generating the spacecraft resource profile and integrates this with the instrument resource profiles. The overall resource profile is then used to generate formal requests to the NCC for TDRSS contact times. Approximately one week prior to the target week, the EOC scheduler will provide the instrument scheduler *or the PI/TL at the IST* with a preliminary resource schedule.

The final scheduling phase begins one week prior to the target week. The instrument scheduler in coordination with the PI/TL at the IST *or the PI/TL at the IST* develops a list of activities required for the instrument based on DARs, maintenance activities, calibrations, and/or spacecraft activities. For a non-complex instrument, an activity deviation list is created. For a complex instrument, an activity list is created. The instrument scheduler is responsible for constraint checking the activities and getting PI/TL approval prior to forwarding the activity list to the EOC scheduler*, for all instruments assigned to it. Similarly, the PI/TL at the IST is responsible for constraint checking the activities prior to forwarding the activity list to the EOC scheduler, if primary planning and scheduling responsibility has been assigned to the PI/TL.*

The EOC scheduler integrates all the instrument and spacecraft activities and performs conflict resolution to produce a detailed activity schedule. The EOC scheduler notifies the instrument scheduler *or the PI/TL at the IST* of any activities that were rejected due to conflict. Some iteration of this process may then be required to finalize the detailed activity schedule.

3.2.2 Command Management

Two days prior to the target day the EOC scheduler and *the PI/TL at the IST* receive the detailed activity schedule. *For some instruments, on a pre-negotiated basis, the PI/TL at the IST* is responsible for the generation and validation of their instrument microprocessor loads and instrument commands (note: generation and validation of the instrument flight software loads remain the responsibility of the PI/TL using non-ECS tools). *For the remaining instruments, the EOC scheduler is responsible for the generation and validation of instrument microprocessor loads and instrument commands.* The *PI/TL at the IST* forwards the instrument microprocessor loads and instrument commands to the EOC. The EOC scheduler is responsible for generating an integrated spacecraft load that includes: Spacecraft Control Computer (SCC)-stored commands and tables, flight software loads and updates; and instrument microprocessor memory loads. Additionally, the EOC scheduler generates corresponding ground scripts. The ground script contains directives necessary to uplink the integrated loads for each spacecraft, dump the spacecraft recorder and process real-time housekeeping data.

3.2.3 Real-Time Processing

The alternative operations concept for real-time processing can be effectively categorized into three phases: pre-contact, contact, post-contact. The EOC Operations Controller leads the shift operations, which encompass the three phases, for all spacecraft.

During the pre-contact phase, the EOC command activity controller initiates the EOC ground script in preparation for the upcoming contact.

Once contact with the spacecraft has been accomplished, the EOC will automatically ingest and process real-time telemetry data. At the EOC, the real-time telemetry data shall consist of spacecraft and instrument housekeeping telemetry data as well as instrument engineering telemetry data. The EOC spacecraft evaluator monitors the health and safety of the spacecraft and its subsystems, while the EOC instrument evaluator monitors the health and safety of the instruments. The PI/TL, optionally, may also be monitoring the health and safety of their instrument. The EOC command activity controller coordinates and verifies all uplink activities during the contact. (Nominally, all real-time commanding is preplanned and facilitated by the EOC ground script. However, real-time commands may be initiated by the EOC command activity controller.) The PI/TL at the IST is notified of the uplink status of instrument commands. The EOC instrument evaluator verifies command execution status for instrument commands.

During post-contact, the EOC automatically ingests spacecraft recorded telemetry data that was played back to the ground during the contact. The EOC spacecraft evaluator verifies successful receipt of this data.

3.2.4 Spacecraft and Instrument Analysis

The Analysis service provides the EOC spacecraft engineers and the EOC instrument engineers with a set of tools to: perform trend analysis; performance analysis; resource management; configuration management and anomaly resolution for each spacecraft and its instruments. The EOC spacecraft engineers routinely analyze housekeeping telemetry trend data on the spacecraft subsystems to identify performance fluctuation issues. Upon identifying a problem, the EOC spacecraft engineer recommends a corrective action. If the corrective action is not time critical, it is scheduled as a spacecraft activity for the EOC scheduler. If the corrective action is time critical, the corrective action will be performed by the EOC command activity controller during the next available contact. Similarly, either the EOC instrument engineer or the PI/TL at the IST may recommend corrective action for an instrument. Depending on the time criticality, either an instrument activity is scheduled or the EOC command activity controller performs the corrective action during the next available contact.

4. Trades

4.1 FOS Operations

4.1.1 Instrument-Based vs. Multi-Instrument Staffing

Two basic models for staffing instrument operations can be applied to the architectures discussed in this report: instrument-based and multi-instrument. Instrument-based staffing consists of providing dedicated staff to perform instrument operations for each instrument. Multi-instrument staffing consists of providing common staff to perform instrument operations for multiple instruments.

The baseline architecture requires staffing of separate, physical ICCs at GSFC to support each instruments' operations, instrument-based staffing. The ICC operations staff is responsible for: instrument planning and scheduling, instrument monitoring and commanding, and instrument analysis. The distributed nature of this architecture does not allow for economies to be realized via multi-instrument staffing.

The alternative architecture centralizes instrument operations at the EOC. Centralized instrument operations allow EOC operations to utilize either the instrument-based or multi-instrument staffing model. The EOC instrument operations staff is responsible for: instrument planning and scheduling, instrument monitoring and commanding, and instrument analysis. The multi-instrument model allows effective and efficient utilization of the EOC staff, since economies between common operations can be realized. Some examples of these economies include:

a. a scheduler can perform the planning and scheduling function for one or more non-complex instruments

b. an evaluator can perform the instrument monitoring and commanding function for one or more non-complex instruments; and

c. an engineer can perform the instrument analysis function for one or more non-complex instruments.

The topic of operations staffing is more thoroughly addressed in the Flight Operations Segment (FOS) Operations Trade Study for the ECS Project (MR9405V1) .

4.1.2 Operational Complexity vs. Flexibility

Both the baseline architecture and the alternative architecture allow the flexibility for the PI/TL to play an increased role in instrument operations, if desired. The significant difference between the two architectures is the benefits to operations.

Combining the alternative architecture, multi-instrument staffing, and an increased role for the PI/TL in instrument operations; allows for the most efficient use of staffing resources at the EOC. The economies listed under multi-instrument staffing in section 4.1.1 are further enhanced, since some of the planning and scheduling functions and instrument analysis functions can be performed by the PI/TL. The EOC scheduler(s) and engineer(s) would only have to perform instrument operations for those instruments remaining under their responsibility.

The most significant drawback to the alternative architecture, from an operations perspective, is increased complexity. Instrument operations are not performed in a uniform and consistent manner. Responsibility for planning and scheduling activities as well as analysis activities will sometimes belong to the EOC and other times these responsibilities will belong to the PI/TL. On the other hand, these responsibilities would be established in advance (pre-launch) and would be relatively fixed (i.e. they would not float). This would allow for the establishment of well-defined operational procedures that reduce risk associated with the complexity.

4.2 FOS Software

The baseline FOS software was estimated using two key factors: reuse from existing control center programs; and reuse of EOC software within the ICC. The first of these factors, reuse from existing control centers, provides the same base from which to build regardless of the EOC-ICC architecture. The second factor, reuse of the EOC software within the ICC, needs to be considered in this analysis.

Estimates on lines of code (LOC) for FOS software utilized the large similarity between EOC and ICC processing to significantly reduce the cost of the ICC portion of the software. The ICC portion of the software was costed on instrument specific features and the assumption was made that control center generic software would be re-used from the EOC implementation. Eliminating the ICC, and distributing its functionality, does not produce a software savings, since the functionality has not been diminished. All the software specific to instrument operations must still be provided in the alternative architecture.

4.3 FOS COTS

The Baseline COTS summary provided in table 4-3 assumes separate facilities for the EOC and the complement of ICCs. The alternative COTS summary, also provided in table 4-3, considers the new COTS requirements based on a single facility. The following assumptions were made for the EOC alternative COTS requirements:

a. A single LAN will be used for both spacecraft and instrument operations. Therefore, the bridges that were originally required by the baseline ICC do not need to be reflected in the alternative EOC total.

b. Spacecraft and instrument telemetry and command processing can occur on the same hardware string. Therefore, the number of T&C Processors were not increased from the baseline EOC to the alternative EOC. Instead the specifications for these processors would be modified to handle the additional loading required for simultaneous spacecraft and instrument processing.

c. Spacecraft and instrument data management can occur on the same hardware string. Therefore, the number of DMS Processors were not increased from the baseline EOC to the alternative EOC. Instead the specifications for these processors would be modified to handle the additional loading required for simultaneous spacecraft and instrument processing.

d. All the workstation positions from the baseline summary are still valid; this includes both real-time and off-line positions. Therefore, the number of workstations required in the baseline ICC were added to those in the baseline EOC to arrive at the number of workstations required for the alternative EOC.

e. There is some difference between the baseline EOC and ICC archives. Therefore, the baseline EOC RAID quantity was not modified for the alternative architecture; instead, the storage specifications for each RAID would be increased to compensate for the difference.

f. The baseline ICC tape robot was migrated to the alternative EOC for any temporary or high-speed archiving of instrument data.

g. The total number of network interfaces remains unchanged with the exception of the 12 baseline FDDI interfaces that were originally specified for the ICC T&C Processors and the ICC DMS Processors; these were deleted.

h. COTS software must be provided for appropriate processors. All workstations will be equipped with OSF/Motif, Graphics, and Analysis Tools. The high-performance workstations will be equipped with an expert system. All CPUs will be equipped with communications software.

Table 4-1. Baseline/Alternative COTS Summary

Description	Baseline EOC/ICCs Quantity	Alternative EOC Quantity
T&C Processor	3/3	3[1]
DMS Processor	3/3	3[1]
High-Performance Workstation	2/4	6
Medium-Performance Workstation	24/15	39
RAID	2/2	2[2]
8mm DMS Archive	0/1	1
FDDI Interfaces	16/20	24
Concentrators	8/8	16
Ethernet Interfaces	48/30	78
Network Bridges	4/4	4
OSF/Motif SW	32/25	45
Communications SW	31/24	51
DBMS	3/3	3
Graphics SW	26/19	45
Expert System SW	2/2	4
Analysis Tools	26/19	45

[1]Increase processing power and storage requirements

[2]Increase storage requirement

4.4 Conclusion

Both the baseline and alternative architecture presented in this paper support the functional requirements of the ECS FOS. Considerations made during this trade looked at the advantages and disadvantages of each architecture with respect to operations, custom software development, and commercial of the shelf (COTS) product requirements. Other considerations that were not included in this trade, since they were external to the ECS project, include facility requirements and EOS Communications (ECOM) requirements. Table 4-4 provides a comparison of the two architectures based on section 4.1, 4.2, and 4.3.

Table 4-4. Architecture Comparison

Architecture	Advantages	Disadvantages
Baseline	All instrument operations are performed uniformly. Complex instruments requiring an ICC are accounted for in this architecture.	Requires instrument-based staffing. Instrument expertise needed at the ICC. Multiple facilities that are largely redundant in COTS and custom software must be supplied and maintained at GSFC.
Alternative	Supports multi-instrument or instrument-based staffing. Supports flexibility in performing instrument operations. Instrument operations are tailored for each instrument. A single facility at GSFC performs spacecraft and instrument processing, allowing economies in COTS, maintenance of custom software and operations to be realized.	Operational complexity, the EOC coordination of activities is non-trivial. Complex instrument requiring an ICC would require an extension to the architecture.

Sections 4.2 and 4.3 demonstrate that FOS software and COTS costs are not significantly different for the two architectures. The baseline FOS software estimates include considerations for the redundancy between the EOC and the ICC. The scope of this trade study did not include any reduction or change in functionality, therefore, there is no change in the effective lines of code needed for the FOS. The COTS required for the baseline and alternative architecture are not significantly different. The most significant change would be a reduction in quantities for the

T&C Processors, the DMS Processors, and the RAIDs. These reductions in quantity would be at least partially offset by increased processing and storage requirements.

The most significant differences in the baseline and alternative architecture are operational differences. The baseline architecture implies instrument-based staffing and a high degree of uniformity. The alternative architecture provides flexibility supporting either instrument-based staffing or multi-instrument staffing. Additionally, the alternative architecture combined with multi-instrument staffing allows optimization of instrument operations.

A recommendation to pursue the alternative architecture proposed in this paper is made based on two factors: 1) the assumption that current and future instrument manifests are non-complex; and 2) the desire for flexibility in performing instrument operations at the IST. If in the future a complex instrument requiring an ICC presents itself, the EOC/IST architecture could be expanded to include this functionality.

Abbreviations and Acronyms

BAP	baseline activity profile
CCSDS	Consultative Committee for Space Data Systems
CDRL	Contract Data Requirements List
COTS	commercial off-the-shelf
CPU	central processing unit
DADS	Data Archive and Distribution System
DAR	data acquisition request
DID	data item description
DMS	Data Management Service
ECS	EOSDIS Core System
EDOS	EOS Data and Operations System
ELOC	effective lines of code
EOC	EOS Operations Center
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
ESDIS	Earth Science Data and Information System
FDDI	fiber distributed data interface
FOS	Flight Operations Segment
GSFC	Goddard Space Flight Center
ICC	instrument control center
IMS	information management system
IP	international partner
IST	instrument support terminal
IWG	Investigator Working Group
LAN	local area network
LOC	lines of code
LTIP	long term instrument plan
LTSP	long term science plan
NASA	National Aeronautics and Space Administration

NCC	Network Control Center
OSF	Open Systems Foundation
PI	principal investigator
PI/TL	principal investigator/team leader
RAID	redundant array interchangeable disk
RT	real-time
SCC	spacecraft control computer
SW	software
T&C	Telemetry and Command
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TL	team leader
TOO	target of opportunity